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Improving Pulping Efficiency Through Microwave Treatment

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# Improving Pulping Efficiency Through Microwave Treatment

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## Abstract

Microwaving pine chips in either white liquor or water at low power decreases the quantity of rejects produced in the 30-90 kappa region when the chips are subsequently pulped. A similar effect occurs when cooked fibers are microwaved. Micrographs of irradiated wood show evidence of local internal pressure being developed within the wood matrix, probably because of the expansion of water. It is proposed that this pressure opens up hydrophobic regions in wood and enables water or liquor to enter therein. As a result, the knotty regions in cooked chips disintegrate more easily and lead to lower rejects. An increase in fiber length is also realized, most likely because the knots are less brittle. The economics suggest that the technology is best applied to the irradiation of knots (rejects) prior to recooking.

## Introduction

We have previously shown that microwaving green wood under low-headspace conditions enhances the diffusion of water present in the wood matrix (Hooda and Banerjee 2000). Other benefits of microwaving wood with and without added chemicals have been reported. Davis and Young (1989) showed that microwaving accelerates delignification in solvent pulping. It increases the degree of sulfonation of hardwood and softwood chips (Law *et al.* 1992). It also facilitates bleaching; the brightness of pulp sprayed with hydrogen peroxide increased over a conventionally treated control with much lower use of bleach (Hageman *et al.* 1986). Recently, Hasan *et al.* (2001) showed that microwaving logs at high power decreased the quantity of rejects when the log was subsequently chipped and pulped. Approximately 30% of the moisture was lost during irradiation and the improved pulping behavior was ascribed to the disruption of the wood tissue structure by the escaping steam. We have found that pulping efficiency improves when chips are microwaved under low power and any water loss is insignificant (Banerjee and Malcolm 2002). In this paper we develop a mechanism for the process and identify a practical application.

## Materials and Methods

### *Pulping experiments*

Pine chips were obtained from Weyerhaeuser, Inland Container, and Riverwood International mills in Georgia. In one set of experiments the chips (500 g. oven-dried basis, 1.3-cm thick) were microwaved continuously with a Cober unit in white liquor (30% sulfidity, 18.8% active alkali, wood-to-liquor ratio 1:4 v/v) at 150W until the charge reached 80°C. The power was then applied intermittently to maintain temperature at 80-95°C for 25 minutes. Temperature was monitored with a fiberoptic sensor. The chips were then cooked at various H-factors. In another set, the chips were cooked conventionally, drained, and the fibers (with their associated liquor) microwaved for a total of four minutes. They were then disintegrated for 7 minutes in a British disintegrator at 3,000 rpm and screened through a Somerville flat screen with 0.015-cm slots. The two sets are termed "pre-treated" and "post-treated", respectively. Finally, a set of

chips was microwaved in water and then pulped as above. Control measurements were made in each case with conventionally cooked pulp. Knots were collected from the pulper rejects at the Rayonier mill at Jesup, GA, and were microwaved at 500W to maintain 80-95°C for 25 minutes.

#### *Liquor uptake*

Pine chips (MC: 56% green basis) were saturated to an MC of 66% by immersing them in water under vacuum for 10 minutes and then breaking the vacuum. The cycle was repeated four times until the chips sank. Both sets of chips (MC: 56% and 66%) were then soaked separately in white liquor and microwaved at 100W for various periods. The charge was placed in a capped Teflon container with a narrow opening for pressure relief. The power was cycled to maintain the temperature at 80-95°C and was applied during roughly half the total period that the wood spent in the microwave unit. A control set of chips was oven-heated to the same temperature and for the same period as the microwaved material.

#### *Microscopy-related experiments*

A 45-year-old pine tree was cut into circular pieces of approximately 12 cm in length and 30 cm in diameter. The disks were coated immediately with white vaseline and stored cold under water. Blocks (3 x 2 x 1.5 cm) were cut from both sapwood and heartwood. Samples were treated in one of three ways. For the microwaving work the pieces were wrapped in plastic to minimize drying and were microwaved continuously at 150W for five minutes. Samples prepared for scanning electron microscopy were prepared through solvent exchange (aqueous ethanol and acetone) drying. The blocks were water saturated by placing them in water and aspirating until they reached a constant weight. They were microtomed at a width of 120-150  $\mu$  to avoid damage to the canal. Epoxy or Spurr resin was used in some cases to embed the samples. Micrographs were taken with a JSM - 35C instrument.

### **Results and Discussion**

Microwaving chips in white liquor altered the yield curve as shown in Figure 1; the screened yield is higher in the 30-90 kappa region. These results pertain only to the Flint River chips, since the results from all three batches plotted together show high scatter because of batch-to-batch chip variability. Nevertheless, the general shape of the curve from each batch of chips was similar in that they intersected the control curve at kappa 85 and converged with it at lower kappa as shown by the "pre-treated" curve in Figure 1. The total yield remained unchanged, indicating that microwaving (under our conditions) does not significantly increase the amount of lignin removed. Surprisingly, a similar yield curve was obtained when the cooked pulped was microwaved, as shown by the "post-treated" curve in Figure 1.

The increase in screened yield in the 30-90 kappa region in Figure 1 must lead to a corresponding decrease in rejects. The results from all three sets of chips are shown in Figure 2. Here, the rejects are expressed as a fraction of the total yield, so that variability in furnish is reduced. Note that Figure 2 complements Figure 1 in that the curves intersect at kappa 90 and converge at lower kappa. Clearly, microwaving decreases rejects in the mid-kappa range. The rejects from microwaving were much more homogenous than those conventionally obtained. This suggests that microwaving enhances liquor penetration into the fiber bundles that resist pulping, thereby decreasing the quantity of the rejects. The convergence of the yield curves in Figure 1 at lower kappa is understandable, since the level of rejects is low here and the screened

yield approaches the total yield. The finding that the screened yield is lower for the microwaved material at kappa 85 and above is puzzling. Possibly, microwaving facilitates lignin recondensation.

The finding that similar yield curves resulted from either microwaving chips in white liquor, or the cooked fiber itself, suggested that increased white liquor ingress into the chips was not responsible for the decrease in rejects. In order to confirm this hypothesis chips were soaked in white liquor and the loss of sodium and sulfur from the liquor was measured after microwaving. The results, presented in Figure 3, demonstrate increased uptake in the microwaved material. Liquor ingress is higher for the saturated chips, possibly because air bubbles (which may impede water movement) are removed. Microwaving increases the total carbon content of the residual liquor as illustrated in Figure 4. The decrease in sodium or sulfur during microwaving in Figure 3 is related ( $r^2 > 0.97$ ) to the corresponding increase in total carbon in Figure 4, confirming the cause-and-effect relationship. The increase in dissolved lignin is quite modest and is consistent with the results in Figure 1 where the total yield is unchanged. Hence, we conclude that increased liquor ingress is a contributing, but not the major factor responsible for the changes in the yield curve.

An alternate mechanism is that microwaving opens up the hydrophobic regions in the furnish (*e.g.* knotty areas and shives) and facilitates transport of liquid to and from these sections which would then soften. These regions would now disintegrate more easily prior to screening. If this were the case, then pulping chips microwaved in water instead of in white liquor should also lead to lower rejects. The results in Table 1 confirm this position. The screened yields for the microwaved samples are higher and the quantity of rejects lower than those for the control in the mid-kappa region. The shive count is also lower for the irradiated samples. The differences disappear at about kappa 100.

The above results suggest that microwaving opens up occluded regions in the furnish that would otherwise end up as shives or knots. Detail into the effect of microwaving on cell structure was obtained through microscopy (Wild 2000). Microwaving sapwood led to flattening of the epithelial cells and rupture of the resin canals, as shown in Figure 5. Similar results were obtained upon oven-heating sapwood, although the damage was less severe. In contrast, microwaving or heating heartwood led to much more modest change. While flattening of the epithelial cells occurred to some degree, the resin canals were not broken. Water absorbs most of the microwave energy, and its lower concentration in heartwood accounts for the smaller changes observed. Sections of a resin canal at the surface of a sapwood sample and of the same resin canal 0.5 cm below the surface were embedded in Spurr resin and imaged. The results, presented in Figure 6, demonstrate that the damage below the surface is much more extensive; the resin canal is deformed and the surrounding parenchyma cells are broken. Hence, microwaving causes internal pressures to be developed within the matrix.

These results are consistent with previous hydrogen-deuterium exchange work (Su et al. 1999) where microwaving increased water access to dry or partially dry wood tissue. The effects observed here are not caused by steam, since no significant loss of water occurs. Rather, we believe that expansion of water in the wood matrix is responsible for the pressure. These pressures

do not develop to the same extent during conventional heating, since the wood heats from the outside in and the pressures are more easily dissipated through convection.

Properties of handsheets from pulped knots are reported in Table 2. Microwaving consistently decreased the dirt count and improved fiber length, but not at the expense of curl. The increase in fiber length may be a consequence of the knotty areas being less brittle because of their increased water content. The rejects from cooks corresponding to the second and third entries in Table 2 were fractionated with a Bauer-McNett classifier. The results, listed in Table 3, show that the rejects from the irradiated knots are smaller.

The economics of microwaving the entire furnish are not attractive. Treating the partially cooked pulp is cheaper, but it still represents an additional unit operation that could potentially bottleneck the process. It is unlikely that the benefits will offset the capital and power costs involved. However, low-power microwaving may well be suitable for the treatment of knots, which are recooked, burned, or discarded. A problem with recooking is that knots frequently add to the shive count, which increases chemical use for bleached grades. If our hypothesis that microwaving softens the knotty regions is correct, then microwaving knots prior to cooking should reduce the dirt count. Knots constitute a small fraction of the tonnage processed and the capital cost of the microwave should be relatively low. Also, the operation would be "off-line" and could not bottleneck the process.

### Summary

Microwaving chips or cooked pulp alters the yield curve by opening up hydrophobic regions in wood to the water or liquor contained in the wood. The effect is believed to be caused by differential expansion of the water and is consistent with previous work (Su *et al.* 1999) where irradiation opened up regions in wood that were otherwise impervious to water. This effect enables the cooked chips to disintegrate more easily and increases the screened yield at the expense of the rejects. An increase in fiber length is also realized. The economics suggest that the handling of knots may be a good candidate for this technology.

### Acknowledgments

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<b>Table 1: Properties of pulp from chips microwaved in water</b>				
	<b>kappa no.</b>	<b>percent od yield (screened)</b>	<b>percent rejects</b>	<b>shives/10,000 fibers</b>
control	51.3	47.5	0.75	164
irradiated	53.6	49.0	0.32	145
control	52.7	47.5	0.25	101
irradiated	55.5	48.7	0.38	69
control	80.8	45.2	6.1	247
irradiated	80.3	49.1	3.4	183
control	80.1	47.3	3.8	161
irradiated	76.2	47.9	1.8	114
control	92.6	40.6	11.4	326
irradiated	96.2	42.1	12.6	406
control	96.5	42.8	10.3	372
irradiated	94.2	40.9	10.5	365

Table 2: Properties of handsheets from microwaved knots			
	mean fiber length (mm) <sup>1</sup>	mean curl	dirt count (ppm)
<i>kappa 32</i>			
control	2.16	0.09	84
irradiated	2.43	0.125	59
<i>kappa 35 (set D)</i>			
control	2.16	0.09	42
irradiated	2.43	0.125	34
<i>kappa 36 (set E)</i>			
control	2.16	0.087	102
irradiated	2.48	0.11	78
<i>kappa 49 (set F)</i>			
control	2.29	0.115	275
irradiated	2.58	0.102	189
<i>kappa 29 (set G)</i>			
control	2.24	0.106	123
irradiated	2.41	0.107	83
<sup>1</sup> length-weighted			

Table 3: Bauer-McNett distribution (in percent) of rejects from cooked knots				
mesh:	>4	4-8	8-14	14-200
<i>kappa 35</i>				
control	1.99	0.60	0.35	1.01
irradiated	0.94	0.28	0.51	1.32
<i>kappa 36</i>				
control	3.70	0.62	1.05	1.19
irradiated	2.87	0.34	0.98	1.14



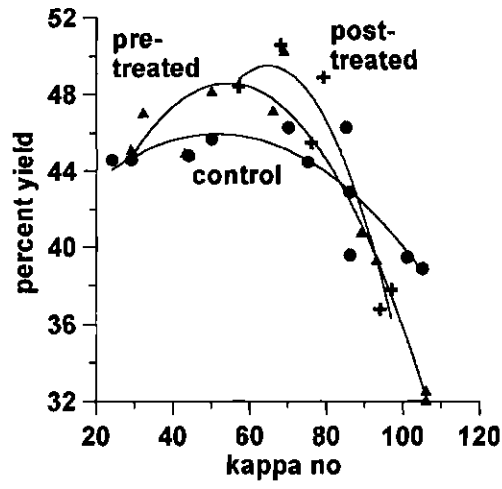


Figure 1: Effect of pre- and post-treatment on screened yield.

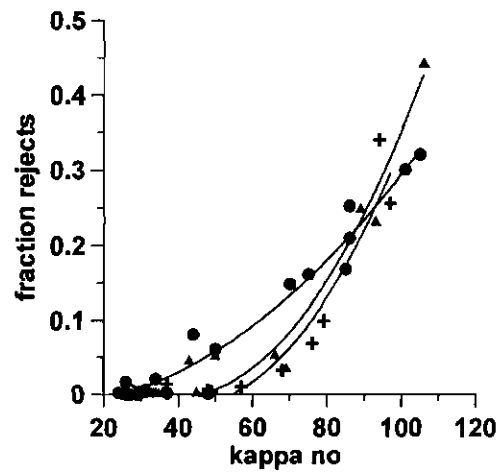


Figure 2: Variation of rejects (as a fraction of total yield) with kappa number. The circles, triangles, and plus signs represent control, pre-, and post-treated measurements, respectively.

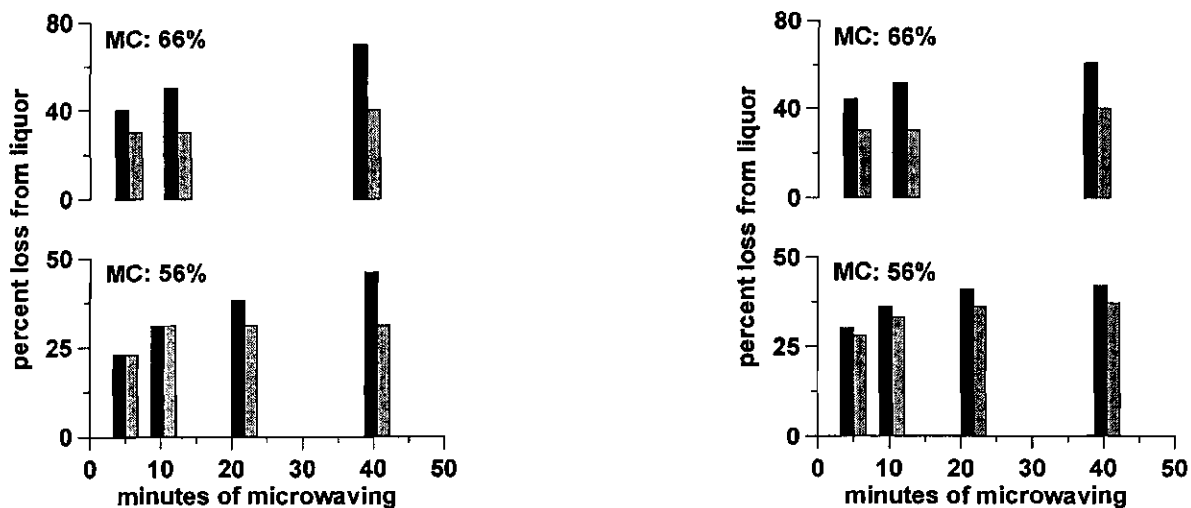


Figure 3: Loss of sulfur (left) and sodium (right) from white liquor during microwave (black) and thermal (hatched) treatment.

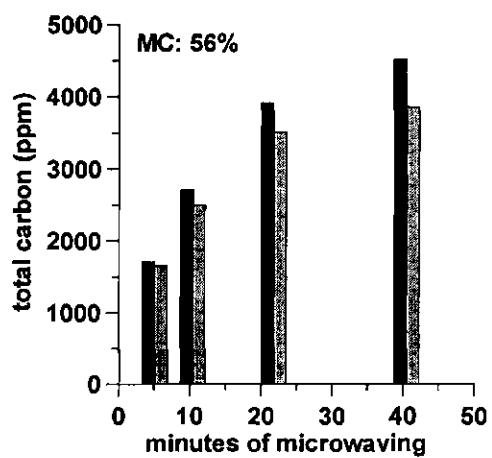


Figure 4: Total carbon concentrations in liquor during microwave (black) and thermal (hatched) treatment.

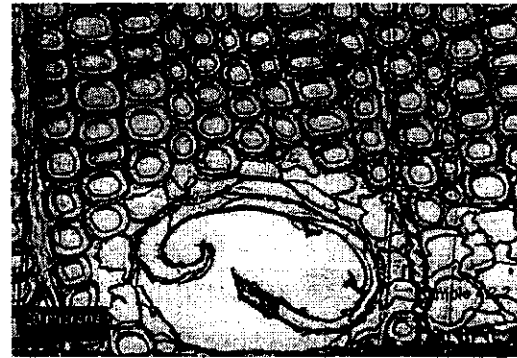
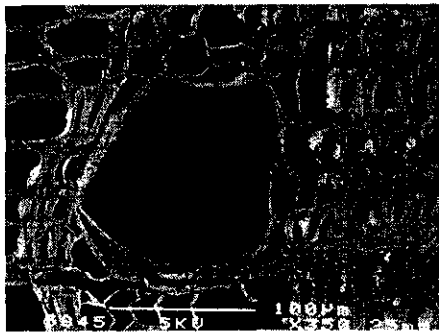


Figure 5: Cross-sectional views of microwaved sapwood resin canals.  
The specimen on the right was embedded in epoxy resin.

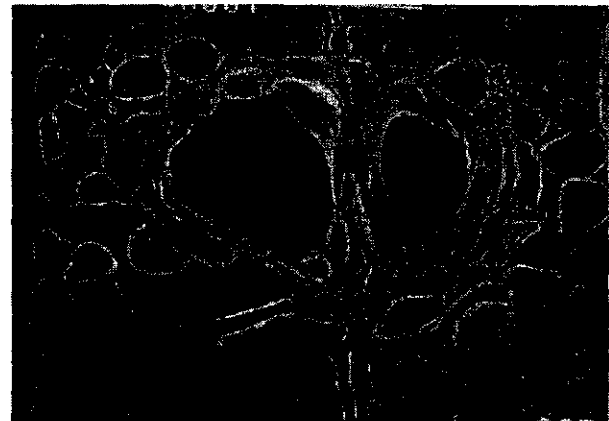
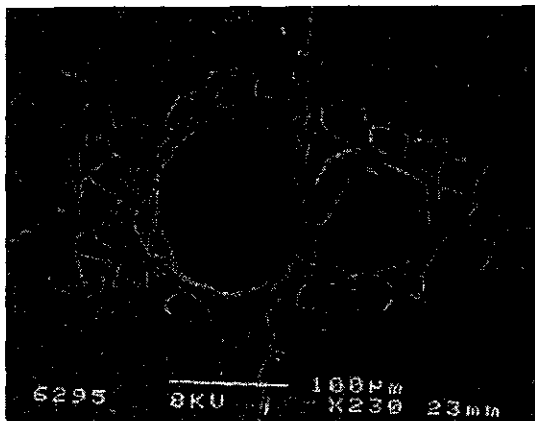


Figure 6: Cross-sectional view of microwaved sapwood resin canals  
taken at the surface (left) and at 0.5 cm below the surface (right).